The salar-isovector sector in the extended Linear Sigma Model*

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We study basic properties of scalar hadronic resonances within the so-called extended Linear Sigma Model (eLSM), which is an effective model of QCD based on chiral symmetry and dilatation invariance. In particular, we focus on the mass and decay width of the scalar-isovector state $a_0(1450)$ and perform a numerical study of the propagator pole(s) on the unphysical Riemann sheets.

It is nowadays recognized that the scalar sector of hadronic particles is not well described by the ordinary $q\bar{q}$ picture based on a simple representation of $SU(3)$ flavour symmetry. One very simple reason is the mere fact that the number of physical resonances is much larger than the number of states that can be constructed within a $q\bar{q}$ picture. For instance, in the scalar-isovector sector it is possible to build up only one such state, though two isotriplets are definitely established, the resonances $a_0(980)$ and $a_0(1450)$ [1].

The extended Linear Sigma Model includes (pseudo)scalar as well as (axial-)vector states [2,3]. In this model, the scalar-isovector state is identified with the resonance $a_0(1450)$. In this report, we use the parameters of Ref. [3] in order to calculate the propagator of $a_0(1450)$: in this way we can test the effect of loops on this broad scalar state. Then, we focus on the region below the $K\bar{K}$ threshold and try to find out whether $a_0(980)$ emerges as a companion pole in the propagator.

For our purpose it is sufficient to give only the relevant interaction part of the Lagrangian for the neutral state a_0^0:

$$\mathcal{L}_{\text{int}} = A a_0^0 \eta \pi^0 + B a_0^0 \eta' \pi^0 + C a_0^0 (K^0 \bar{K}^0 - K^- K^+) \;, \quad (1)$$

where π^0, η, η', K are the pseudoscalar mesons, and the constants A, B, C are combinations of the coupling constants and masses taken from Ref. [3]. They are constructed in such a way that the decay amplitude for each channel, $-i\mathcal{M}_{ij}$, is momentum independent. The optical theorem for Feynman diagrams can then be applied to compute the imaginary part of the corresponding self-energy loop $\Pi_{ij}(s)$, regularized by a Gaussian 3d-cutoff function with cutoff scale $\Lambda = 0.85$ GeV:

$$\int \mathrm{d}\Gamma \, |{-i}\mathcal{M}_{ij}|^2 = \sqrt{s}\,\Gamma_{ij}^{\text{tree}}(s) = -\operatorname{Im}\Pi_{ij}(s) \;, \quad (2)$$

where $\Gamma_{ij}^{\text{tree}}$ is the tree-level width coming from the model and $\mathbf{k}$ is the three-momentum of one of the emitted particles in the decay of the a_0^0 in its rest frame. The real part is obtained by the dispersion relation

$$\operatorname{Re}\Pi_{ij}(s) = \frac{1}{\pi} \fint \mathrm{d}s' \, \frac{\operatorname{Im}\Pi_{ij}(s')}{s - s'} \;. \quad (3)$$

After that, the self-energy is analytically continued to complex values, $s \to z$, while the continuation into the appropriate unphysical Riemann sheet(s) can be done by adding the discontinuities for each channel,

$$\Pi_{ij}^c(z) = \Pi_{ij}(z) + \text{Disc}\,\Pi_{ij}(z) \;, \quad (4)$$

where $\text{Disc}\,\Pi_{ij}(s) = 2i \lim_{\epsilon\to 0^+} \operatorname{Im}\Pi_{ij}(s + i\epsilon)$ and the superscript c indicates the continued function on the next sheet. Note that the appropriate sheet is taken to be the one closest to the physical region.

The complex propagator pole on the sheet nearest to the physical region has coordinates $\sqrt{s} = (1.412 - i0.141)$ GeV, hence a decay width of $\Gamma = 282$ MeV (in good agreement with both the tree-level result from our model and the experiment) and a mass of 1.412 GeV. While the (bare) mass $M_0 = 1.363$ GeV coming from the eLSM differs from the experimental value by at least ~ 50 MeV, the pole mass (as the real part of the propagator pole) lies within the experimental error. Thus, the inclusion of loops represents an improvement of the tree-level results. However, all in all, the loop contributions have just a minor influence on the tree-level values: this is important because it confirms that the fit of Ref. [3] is robust. One should perform this check for all other broad states entering in the eLSM.

Another interesting observation is the fact that we do *not* find a companion pole of $a_0(1450)$: the resonance $a_0(980)$ does not emerge for the values of the parameters determined in Ref. [3]. This result is robust upon variations of the parameters. As a possible outlook for future work one should try to include the $a_0(980)$ as a tetraquark state into the eLSM and/or perform a full scattering analysis so as to investigate the emergence of this resonance in more detail.

References

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